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(71) Applicant: Juniper Networks, Inc.
Sunnyvale, CA 94089 (US)

(72) Inventor: Popper, Ambroise
75008 Paris (FR)

(74) Representative: Casalonga, Axel
BUREAU D.A. CASALONGA - JOSSE
Paul-Heyse-Strasse 33
80336 München (DE)

(54) Estimation of frequency offset, for use with short data bursts

(57) Frequency offset estimation, suitable for use with bursts of up to 200 symbols, is performed in two stages. Firstly, an initial estimate is made, using the preamble. Secondly, during the remainder of the burst, those decisions which are deemed unreliable are not used in the estimation.

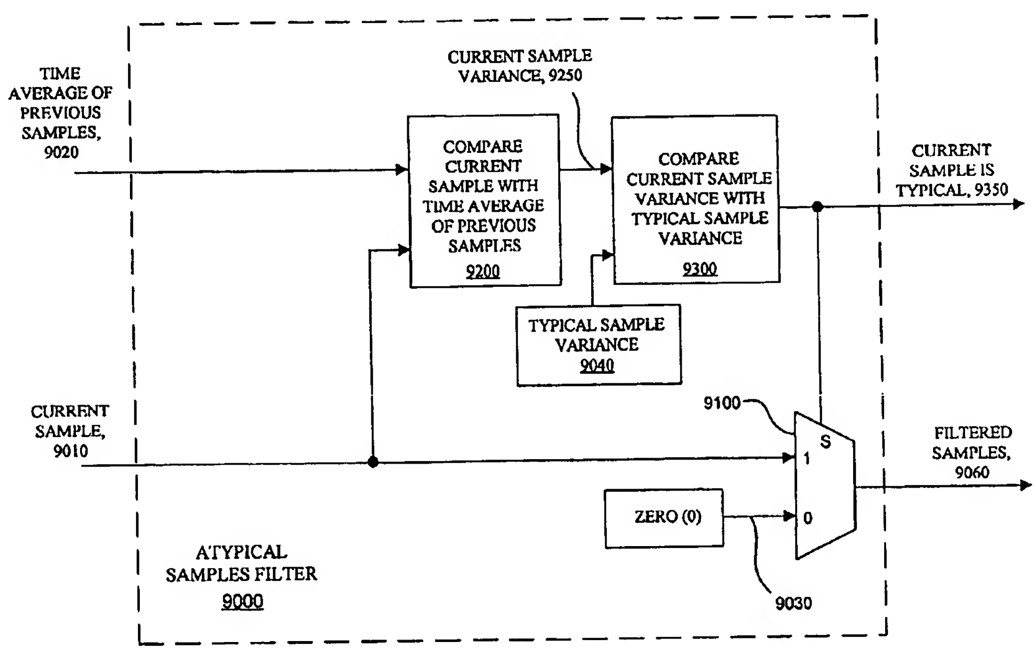

Fig. 5

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Description

Background

[0001] Figs. 1A and 1B illustrate a prior-art Hybrid Fiber-Coax (HFC) cable system 100 that is compatible with the cable industry standard Data over Cable System Interface Specification (DOCSIS) for providing Internet access to cable customers via so called Cable Modems (CMs). Fig. 1A is a top-level view of the cable system. Fig. 1B provides additional detail of the Customer Premises Equipment (CPE) of Fig. 1A. In Fig. 1B, CM 4000 provides a computer industry standard Ethernet interface to PC 5000 and bridges the Ethernet interface with the coax distribution of the cable system. CM 4000 internally implements both an RF Modulator and an RF Demodulator for communications over the coax in accordance with the DOCSIS standard.

[0002] An RF Modulator 3000 and RF Demodulator 1000, complementary to those of the cable modem, are implemented in a DOCSIS compatible Cable Modem Termination System (CMTS) 500, which as the name implies, provides termination for the Cable Modem of the CPE. Multiple instances of Modulator 3000 and Demodulator 1000 are provisioned to support all customers with CM service. Control, MAC, Framing 2000 bridges all of the provisioned DOCSIS RF interfaces with one or more packet-based networks. These packet networks may include local area networks, intranets, and the Internet. While Fig. 1A shows the CMTS 500 implemented in a Head End or Primary Hub, theoretically it is possible to implement the CMTS anywhere upstream from the CM. Each demodulator 1000 provides outputs to the Control, MAC, Framing 2000 that include Detected Symbols 1200 and a Frequency Offset Estimate 1300.

[0003] While the transmitter of the CM upstream modulator and the complementary receiver in the CMTS demodulator are theoretically provisioned for identical frequencies, frequency offsets may occur for a variety of reasons. These reasons include errors in the local oscillators of the CM modulator (used to transmit the signal burst at the provisioned frequency) or CMTS front-end (used to down-convert the received signal burst to baseband) as well as the use of up- and down-conversion processes applied to the upstream channels over the path from CM to CMTS. These conversion processes are used to combine and split multiple channels over common communication paths for economic transport. Depending on severity and other system issues, frequency offsets could degrade Bit Error Rates (BERs), increase latencies, or completely prevent signal capture. However, these problems may be avoided by using closed loop methods to minimize or eliminate the offsets.

[0004] In CMTS applications, system operation may be conceptually divided into normal data traffic conditions (traffic mode) and so-called ranging periods (ranging mode). Ranging is a closed loop process by which the CMTS manages the timing, power level, offset frequency, and equalization for the transmitter of each CM. Ranging is performed whenever a CM is initialized and registered by the network and also periodically (at regular time intervals) to update its calibration. The ranging calibration process is performed for every CM on the channel and enables the system to smoothly operate at high effective throughput during traffic mode.

[0005] As applicable to the cable system of Fig. 1A, during ranging, a Frequency Offset Estimate 1300 is made in Demodulator 1000 of the CMTS and provided to the Control, MAC, and Framing 2000. The control functions of this block then send one or more commands downstream to the corresponding CM, remotely adjusting its transmitter frequency until the frequency offset observed at Demodulator 1000 is reduced to within predefined acceptable limits. Once set during ranging, the offset frequency adjust continues to be used by the CM during subsequent traffic mode operation. The ranging determined offset frequency adjust thus effectively eliminates any frequency offset observed by the CMTS, regardless of the source or sources of the offset.

[0006] Ranging represents the most problematic operating condition for determining the frequency offset estimate, as the frequency offset is generally large during ranging and other CM characteristics are not yet calibrated for optimal performance. Accordingly, symbol errors may be frequent. During traffic mode, the CM is operating with a much smaller effective frequency offset due to the compensating offset frequency adjust assigned by the CMTS during ranging and overall CM operation is optimally calibrated. Symbol errors are significantly reduced.

Demodulator Operation

[0007] Fig. 2A provides a general conceptual block diagram of the digital burst Demodulator 1000 in the CMTS 500. Front-End 600 isolates one modulated carrier from the carrier multiplex in the Received Spectrum 1100, baseband converts the signal, and passes the resulting signal 1105 to the Burst and Timing Synchronization circuit 1500. (In other contexts the Front-End 600 might be considered as a function prior to, and not part of, the demodulator.) The Recovered Signal Samples 1106, at the output of circuit 1500, are discrete signal samples at the symbol rate.

[0008] Equalizer 1600 compensates for signal distortion not compensated by a pre-equalizer in the cable modem (CM) and also suppresses ingress noise. At the output of this stage, the Equalized Signal Samples r_k (1107) are given by:

$$r_k = a_k e^{j\varphi_k} + w_k,$$

where a_k is the transmitted symbol and w_k is the additive

noise. These samples are not yet synchronized in terms of carrier phase.

[0009] Carrier Phase Synchronized Samples 1108 are produced by the Rotator 1700 in conjunction with Phase Estimator 1900. The carrier phase φ_k is given by:

$$\varphi_k = 2k\pi\Delta f T_s + \varphi_0.$$

where Δf is the frequency offset and T_s is the symbol period.

[0010] Let $\hat{\varphi}_k$ be the estimated carrier phase used for symbol k. The equalized signal r_k is multiplied by

$$\exp\left(-j\hat{\varphi}_k\right)$$

within Rotator 1700 so as to decide symbol a_k by Detector 1800. The decision on symbol a_k is denoted d_k, which is output as Detected Symbols 1200.

[0011] The quantity $p_k = r_k \dot{d}_k$ is subsequently computed. For CMTS and other applications having a high value of the frequency drift, quasi-differential demodulation is preferred, and the carrier phase recovery algorithm only uses the last value of p_k to determine the carrier phase. In such cases, the estimated carrier phase can thus be written as:

$$\hat{\varphi}_k = \arg(r_{k-1}\dot{d}_{k-1})$$

Prior Art Frequency Estimators

[0012] Frequency Offset Estimator 8000 provides Frequency Offset Estimate 1300, an estimate of the observed frequency offset of the received signal. Prior art frequency estimation techniques for general burst demodulator applications have used phase slope computations and related time averaging, or have been based on the autocorrelation function of the signal. Fig. 2B illustrates a particular prior art Frequency Offset Estimator (8000-PA-AC) based on autocorrelation of the signal. Fig. 2C illustrates a particular prior art Frequency Offset Estimator (8000-PA-PS) based on phase slope computations. Fig. 2D provides additional detail of the Phase Slope Computation 8100, of Fig. 2C.

[0013] The prior art frequency estimation techniques provide satisfactory precision for more general burst demodulator applications that use long bursts of known symbols (such as found in long message preambles) or admit to time averaging over multiple consecutive bursts. Unfortunately, both isolated short bursts and symbol errors are characteristics of CMTS applications, particularly during ranging. CMTS applications employ isolated short ranging bursts of approximately 200 symbols, consisting of a very short preamble (typically 20-30 known symbols) and a short data block consisting of symbols extracted by the local detector. Due to noise and other factors, generally including the existence of frequency offsets, the output of the detector will not be free of symbol errors.

[0014] In view of the above, it is useful to make a detailed examination of the performance of the prior art frequency estimator based on the autocorrelation function of the signal. As shown in Fig. 2B, the prior art autocorrelation estimator bases the frequency estimation on the computation of $\delta_k = p_k \dot{p}_{k-L}$. By proper normalization of the time average of δ_k, the frequency can be estimated as:

$$\hat{\Delta f} = \frac{\arg\left(\sum_{k=L+1}^{N}\delta_k\right)}{2\pi T_s L}$$

where N designates the number of symbols in the burst at hand, and L is a delay parameter defined in the Correlator 8620 in Fig. 2B.

[0015] Suppose that a symbol error occurs at the k_0 decision instant. With the assumed QPSK signal format, this leads to an instantaneous phase error of $\pm\pi/2$. Furthermore, as quasi-differential demodulation is used, this $\pm\pi/2$ phase-error appears in all subsequent symbol decisions, and also in all p_k values computed after k_0.

[0016] Thus, the phase of p_k for the theoretical frequency estimator has a constant slope except for one discontinuity of $\pm\pi/2$ when the error occurs. Consequently, the phase of δ_k (recall that $\delta_k = p_k \dot{p}_{k-L}$) is centered around the desired value, except for L values with an error of $\pm\pi/2$. The average phase of δ_k over the burst size is then shifted by $\pm L(\pi/2)/(N-L)$. Since the normalized frequency estimate $\Delta f T_s$ is obtained by dividing this average phase by $2\pi L$, it clearly contains an error of $\pm 0.25/(N-L)$.

[0017] Consider a particular quantitative example using the foregoing analysis. Suppose that we want to have an estimation precision of 10^{-4} for a burst length of 200. Should a single decision error occur during this burst, this error would result in a normalized frequency estimation error of approximately 0.25/200, or approximately 10^{-3}. This is an order of magnitude greater than the desired accuracy of 10^{-4}. Those skilled in the art will see that a similar analysis, with similar results, can be made for a phase slope based estimator.

[0018] The prior art frequency estimation approaches are clearly not well suited to CMTS applications, as it has been seen that even a single symbol error results in substantial errors. Improved frequency estimation methods and devices are needed that provide precise frequency estimates for short bursts in the presence of

symbol errors. New frequency estimation approaches are needed that can be performed on one single burst, without the need for averaging the results of several consecutive bursts. In particular, improved frequency estimation techniques are needed that offer superior performance for CMTS applications.

Brief Description of Drawings

[0019]

Figs. 1A and 1B illustrate a prior-art HFC cable system. Fig. 1A is a top-level view of the cable system. Fig. 1B provides additional detail of the CPE of Fig. 1A.

Fig. 2A provides internal architectural detail of Demodulator 1000 of Fig. 1A.

Fig. 2B provides detail of a prior art Frequency Offset Estimator 8000-PA-AC, based on Autocorrelation of the signal, and having application in the Demodulator 1000 of Fig. 2A.

Fig. 2C provides detail of a prior art Frequency Offset Estimator 8000-PA-PS, based on Phase Slope Computation, and having application in the Demodulator 1000 of Fig. 2A.

Fig. 2D provides additional detail of a prior art Phase Slope Computation Function 8100, as used in Fig 2C.

Fig. 3 provides detail of a first illustrative embodiment (8000-AC) of a Frequency Offset Estimator, based on Autocorrelation, in accordance with the present invention, and having application in the Demodulator of Fig. 2A.

Fig. 4 provides detail of a second illustrative embodiment (8000-PS) of a Frequency Offset Estimator, based on Phase Slope Computation, in accordance with the present invention, and having application in the Demodulator of Fig. 2A.

Fig. 5 provides detail of an illustrative embodiment of an Atypical Samples Filter 9000, suitable for application as either the Discard Atypical Correlation Samples Function 8630 of Fig. 3, or the Discard Atypical Phase Slope Samples Function 8200 of Fig. 4.

Summary

[0020] The present invention provides methods and apparatus for generating precise frequency estimates for applications with both short bursts and symbol errors. The invention is practical, easy to implement, robust against decision errors, and requires only one burst to achieve frequency estimation with high precision (around 10^{-4} in $\Delta f T_s$ in the illustrative embodiments).

[0021] The invention performs frequency estimation over both the burst preamble, during which known symbols are transmitted, and also during the burst's data packet, which is subsequent to the preamble and extracted by the local detector. During the preamble, an initial frequency estimate is obtained. This estimate is based on a time average of either phase or correlation samples. Atypical phase or correlation samples, attributable to detector symbol errors during the data packet, are detected and filtered, so as to avoid including the atypical samples in a time-average used to provide the frequency estimate.

[0022] In a first embodiment correlation samples are time averaged, and atypical correlation samples are suppressed prior to correlation time averaging. In a second embodiment, phase slope values are time averaged, and atypical values of phase slope are suppressed prior to phase slope time averaging.

Detailed Description

Atypical Sample Suppression

[0023] Recall that in the presence of a single symbol error, the phase of p_k for the prior art autocorrelation frequency estimator of Fig. 2B has a constant slope except for one discontinuity of $\pm\pi/2$ associated with the symbol error. Consequently, the phase of δ_k is centered around the desired value, except for L values with an error of $\pm\pi/2$. The present invention, illustrated in Figs. 3-5, improves upon the prior art estimator by eliminating the secondary peak via appropriate non-linear filtering. More specifically, the aim of this filtering is to eliminate from the integration on δ_k the values known to be wrong. These values are those whose argument differs from that of the current average of δ_k by more than a certain angle ν.

[0024] In preferred embodiments a preamble of 26 known symbols is used. Thanks to the preamble, it is possible to have a first coarse frequency estimate at the beginning of the data symbols. Using this value, it is possible to determine for each new δ_k whether it should be kept or not in the sum. If it is, this new value of the sum is used to filter the next symbols. Thus, if the coarse estimate provided by the preamble is precise enough, the secondary peaks are totally eradicated. Simulations of the illustrative embodiments have confirmed that the precision of the coarse frequency estimate provided by the preamble does support elimination of the secondary peaks. Those skilled in the art will appreciate that while the above description has focused on the elimination of atypical correlation samples for an autocorrelation frequency estimator, the invention is equally applicable to elimination of atypical phase slope samples for a phase slope computation frequency estimator.

Autocorrelation Embodiment

[0025] Fig. 3 shows an Autocorrelation Frequency Estimator (8000-AC) in accordance with the present invention. As the name suggests, the frequency estimation algorithm is based on the computation of Correlation

Samples $\delta_k = \rho_k\rho^*_{k-L}$ (8625), which ar generated by Correlator 8620.

[0026] The discard atypical values and time averaging functions (8630 and 8640, respectively) operate on an exponential function involving the phase slope. At the output of the Correlation Time Averaging stage 8640, we have $\rho_k \exp(j2\pi L\Delta f_k T)$ 8645, where atypical values have been suppressed by Discard Atypical Correlation Samples 8630. Discard Atypical Correlation Samples 8630 acts such that δ_k has no effect on the running time average whenever the absolute value of $\arg[\delta_k \exp(-j2\pi L\Delta f_k T)]$ is greater than a fixed threshold v.

[0027] Arg(.) 8650 delivers the phase $2\pi L\Delta f_k T$, which is used as unnormalized frequency offset estimate 1300-U. Normalized frequency offset estimate 1300-N may optionally be provided as output.

Phase Slope Computation Embodiment

[0028] Figs. 4 shows a Phase Slope Computation Frequency Estimator (8000-PS) in accordance with the present invention. The Phase Slope Computation 8100 of Fig. 2D, is preferably used as the first stage of the improved Frequency Estimator (8000-PS) of Fig. 4. Within said Phase Slope Computation 8100, the received signal r_k 1107 is multiplied (via 8105) by the complex conjugate of the detected symbol d_k 1200. The function Arg(.) (i.e., the phase calculation function) 8120 gives the phase difference 8110 between the received and detected signals. Slope Computation 8140 computes the phase slope 8150 from two phase-values separated by L samples.

[0029] Phase Slope Time Averaging 8300 outputs an estimate of the frequency offset $2\pi\Delta f_k T$ (1300-U) using the phase slope values computed up to time k. This unnormalized frequency offset, or the normalized frequency offset estimate Δf_k (1300-N), is updated at the symbol rate.

[0030] Discard Atypical Phase Slope Samples 8200 acts to discard the instantaneous phase slope values 8150 which differ from the current unnormalized frequency offset estimate $2\pi\Delta f_k T$ (1300-U) by more than a fixed threshold μ. If the difference between the two signals exceeds μ, then this circuit decides that a symbol error has occurred and that the current slope value should not be included in the time-averaging function. That is, λ_k has no effect on the running time average whenever the absolute value of $2\pi\Delta f_k T-\lambda_k$ is greater than μ. Either the unnormalized frequency offset 1300-U or normalized frequency offset estimate 1300-N may be provided as output to the Control, MAC, Framing 2000 block of CMTS 500.

Atypical Samples Filter

[0031] Fig. 5 provides detail of a conceptual illustrative embodiment of an Atypical Samples Filter 9000, suitable for application as either the Discard Atypical Correlation Samples Function 8630 of Fig. 3, or the Discard Atypical Phase Slope Samples Function 8200 of Fig. 4. This filter acts such that the current sample 9010 has no effect on the running time average of samples whenever the absolute value of the difference between the time average of samples 9020 and current sample 9010 is greater than the typical sample variance 9040. Block 9200 compares Current Sample 9010 with Time Average Of Samples 9020 to generate Current Sample Variance 9250. This in turn is compared against predefined Typical Sample Variance 9040 to produce Current Sample is Typical 9350, a logical binary valued control output. This control can be used directly by a subsequent time averaging circuit to qualify/suppress the use of the current sample. Alternatively, or in combination with direct use, this control can be used to zero the Filter Sample value 9060 provided to the time averaging circuit.

Implementation Considerations

[0032] In comparing the two illustrative embodiments, the phase function on which the phase slope based estimator of Fig. 4 operates is a "wrapped" function that is periodic between $-\pi$ and $+\pi$. The significance of this is that boundary tests and conditional calculations must be performed to "unwrap" this function prior to the computation of the phase slope and thereby the frequency offset. The correlation-based estimator of Fig. 3 has no need to perform the extra phase unwrapping operations, and thus may offer implementation advantages.

[0033] In considering the implementation boundary between hardware (H/W) and software (S/W), remember that the Demodulator 1000 of Fig. 1A does not use the frequency estimation result. Instead it is sent by the CMTS to the CM as an offset-frequency-adjust to control the CM transmit-frequency. This is not a real time procedure, and only one offset frequency adjust is to be sent per burst. However, the frequency error estimate is extracted from a real-time sampled signal with one sample per symbol. In our preferred implementation, all functions are implemented in hardware except the phase calculation in box 8650 and optional normalization in box 8660 of Fig. 3, and the optional normalization in box 8400 in Fig. 4. The reason is that those computations are performed once per burst, which means that they do not need high-speed electronics.

[0034] A fully software implementation would consist of sending the equalized samples r_k and detected symbols d_k to the software and make all computations in software. While such an implementation is within the scope of the present invention, it is not likely to be an efficient implementation. In general, real-time computations (at the symbol rate) are best made in hardware and low-speed computations (at the burst rate) are best made in software.

Conclusion

[0035] Although the present invention has been described using particular illustrative embodiments, it will be understood that many variations in construction, arrangement and use are possible consistent with the teachings and within the scope of the invention. For example, bit-widths, clock speeds, and the type of technology used may generally be varied in each component block of the invention. Also, unless specifically stated to the contrary, the value ranges specified, the maximum and minimum values used, or other particular specifications (such as the desired accuracy of the frequency estimate), are merely those of the illustrative or preferred embodiments, can be expected to track improvements and changes in implementation technology, and should not be construed as limitations of the invention. Functionally equivalent techniques known to those skilled in the art may be employed instead of those illustrated to implement various components or sub-systems. It is also understood that many design functional aspects may be carried out in either hardware (i.e., generally dedicated circuitry) or software (i.e., via some manner of programmed controller or processor), as a function of implementation dependent design constraints and the technology trends of faster processing (which facilitates migration of functions previously in hardware into software) and higher integration density (which facilitates migration of functions previously in software into hardware).

[0036] Specific variations within the scope of the invention include, but are not limited to: the use of any of a variety of techniques for identifying atypical samples and for suppressing their impact on sample averages, the use of any of a variety of preamble lengths and not just via the preferred length of 26 symbols, and the use of either or both of the unnormalized and normalized frequency offset.

[0037] All such variations in design comprise insubstantial changes over the teachings conveyed by the illustrative embodiments. The names given to interconnect and logic are illustrative, and should not be construed as limiting the invention. It is also understood that the invention has broad applicability to other communications and network applications, and is not limited to the particular application or industry of the illustrated embodiments. The present invention is thus to be construed as including all possible modifications and variations encompassed within the scope of the appended claims.

Claims

1. A subsystem for estimating the frequency offset between a transmitter and a receiver, the receiver having signals including pre-detection signal samples and detected symbols, the subsystem comprising:

   a) a first processing stage, coupled to the pre-detection signal samples and the detected symbols, the first processing stage generating first processed samples;
   b) a time averaging stage, having a samples input and a first estimate indication output, the first estimate indication being a time average of the input samples; and
   c) an atypical samples stage, coupled to receive the first processed samples and the first estimate indication, the atypical samples stage having a sample status indication selectively characterizing particular first processed samples as typical.

2. The subsystem of claim 1, further wherein the sample status indication is coupled to the time averaging stage to suppress inclusion of atypical samples.

3. The subsystem of claim 2, further wherein the samples input of the time average stage is coupled to an output of the atypical samples stage.

4. The subsystem of claim 1, further wherein the atypical samples stage provides filtered samples to the samples input of the time average stage, the samples being generated from the first processed samples by suppressing atypical samples.

5. The subsystem of claim 4, wherein zero samples are substituted for the atypical samples to perform the suppression.

6. The subsystem of claim 5, wherein the substitution is performed using a signal multiplexor.

7. The subsystem of claim 6, wherein the multiplexor is controlled by the signal status indication.

8. The subsystem of claim 1, wherein the atypical samples stage creates an intermediate current sample variance.

9. The subsystem of claim 1, wherein the atypical samples stage performs first and second comparison operations, wherein the first comparison operation evaluates the current sample against the average of previous samples and creates a current sample variance, and the second comparison operation evaluates the current sample variance against a typical sample variance.

10. The subsystem of claim 1, wherein the first processing stage includes a correlator and the first processed samples are correlation samples.

11. The subsystem of claim 10, further including a phase calculation stage having an input coupled to

the first estimate indication and generating a second estimate indication, the second estimate indication providing an unnormalized frequency offset estimate.

12. The subsystem of claim 11, further including a normalization stage having an input coupled to the second estimate indication and generating a third estimate indication, the third estimate indication providing a normalized frequency offset estimate.

13. The subsystem of claim 1, wherein the first processing stage performs a phase slope computation, the first processed samples are phase slope samples, and the first estimate indication provides an unnormalized frequency offset estimate.

14. The subsystem of claim 13, further including a normalization stage having an input coupled to the first estimate indication and generating a second estimate indication, the second estimate indication providing a normalized frequency offset estimate.

15. The subsystem of claim 13, wherein the phase slope computation includes a phase calculation sub-stage and a slope computation sub-stage.

16. The subsystem of claim 1, wherein the subsystem is operated over both the burst preamble and during the burst's data packet, and wherein the atypical samples stage does not suppress samples during at least part of the burst preamble.

17. The subsystem of claim 16, wherein the preamble uses 26 known symbols.

18. The subsystem of claim 16, wherein the atypical samples stage does not suppress samples over the entire burst preamble.

19. A method of estimating a frequency offset between a transmitter and a receiver based on the received spectrum at the receiver, the transmitter sending the receiver bursts having a preamble and data, the method comprising:

a) providing processed samples derived from the received spectrum, including a current sample;
b) providing a typical sample variance;
c) generating a time average of the processed samples; and
d) during the burst data, excluding the current sample in the time average when the difference between the current sample and the time average exceeds thé typical sample variance.

20. The method of claim 19, further including:

during the burst preamble, including the current sample in the time average.

21. The method of claim 20, wherein the preamble uses 26 known symbols.

22. The method of claim 20, wherein the processed samples are correlation samples.

23. The method of claim 22, further including calculating the phase of the time average to provide an unnormalized frequency offset estimate.

24. The method of claim 23, further including performing normalization to provide a normalized frequency offset estimate.

25. The method of claim 20, wherein the processes samples are phase slope samples and the time average provides an unnormalized frequency offset estimate.

26. The method of claim 25, further including performing normalization to provide a normalized frequency offset estimate.

27. A burst demodulator for a receiver, the receiver receiving bursts from a transmitter, the burst demodulator comprising:

a) a stage generating pre-detection signal samples;
b) a detector stage generating detected symbols; and
c) a subsystem for estimating the frequency offset between the transmitter and the receiver, the subsystem including

i. a first processing stage, coupled to the pre-detection signal samples and the detected symbols, the first processing stage generating first processed samples;
ii. a time averaging stage, having a samples input and a first estimate indication output, the first estimate indication being a time average of the input samples; and
iii. an atypical samples stage, coupled to receive the first processed samples and the first estimate indication, the atypical samples stage having a sample status indication selectively characterizing particular first processed samples as typical.

28. The burst demodulator of claim 27, wherein the first processing stage includes a correlator and the first processed samples are correlation samples.

29. The burst demodulator of claim 28, further including

a phase calculation stage having an input coupled to the first estimate indication and generating a second estimate indication, the second estimate indication providing an unnormalized frequency offset estimate.

30. The burst demodulator of claim 29, further including a normalization stage having an input coupled to the second estimate indication and generating a third estimate indication, the third estimate indication providing a normalized frequency offset estimate.

31. The burst demodulator of claim 27, wherein the first processing stage performs a phase slope computation, the first processed samples are phase slope samples, and the first estimate indication provides an unnormalized frequency offset estimate.

32. The burst demodulator of claim 31, further including a normalization stage having an input coupled to the first estimate indication and generating a second estimate indication, the second estimate indication providing a normalized frequency offset estimate.

33. The burst demodulator of claim 31, wherein the phase slope computation includes a phase calculation sub-stage and a slope computation sub-stage.

34. The burst demodulator of claim 27, wherein the subsystem is operated over both the burst preamble and during the burst's data packet, and wherein the atypical samples stage does not suppress samples during at least part of the burst preamble.

35. The burst demodulator of claim 34, wherein the preamble uses 26 known symbols.

36. The burst demodulator of claim 34, wherein the atypical samples stage does not suppress samples over the entire burst preamble.

37. A cable modem termination system (CMTS) for a cable system, the cable system including at least one cable modem having a transmitter, the CMTS comprising:

a) a modulator;
b) a network interface including control, media-access-control, and framing functions; and
c) a demodulator coupled to receive bursts from the cable modem transmitter, the demodulator including a stage generating pre-detection signal samples, a detector stage generating detected symbols, and a subsystem for estimating the frequency offset between the cable modem transmitter and the demodulator, the subsystem including

i. a first processing stage, coupled to the pre-detection signal samples and the detected symbols, the first processing stage generating first processed samples;
ii. a time averaging stage, having a samples input and a first estimate indication output, the first estimate indication being a time average of the input samples; and
iii. an atypical samples stage, coupled to receive the first processed samples and the first estimate indication, the atypical samples stage having a sample status indication selectively characterizing particular first processed samples as typical.

38. The CMTS of claim 37, wherein the first processing stage includes a correlator and the first processed samples are correlation samples.

39. The CMTS of claim 38, further including a phase calculation stage having an input coupled to the first estimate indication and generating a second estimate indication, the second estimate indication providing an unnormalized frequency offset estimate.

40. The CMTS of claim 39, further including a normalization stage having an input coupled to the second estimate indication and generating a third estimate indication, the third estimate indication providing a normalized frequency offset estimate.

41. The CMTS of claim 37, wherein the first processing stage performs a phase slope computation, the first processed samples are phase slope samples, and the first estimate indication provides an unnormalized frequency offset estimate.

42. The CMTS of claim 41, further including a normalization stage having an input coupled to the first estimate indication and generating a second estimate indication, the second estimate indication providing a normalized frequency offset estimate.

43. The CMTS of claim 41, wherein the phase slope computation includes a phase calculation sub-stage and a slope computation sub-stage.

44. The CMTS of claim 27, wherein the subsystem is operated over both the burst preamble and during the burst's data packet, and wherein the atypical samples stage does not suppress samples during at least part of the burst preamble.

45. The CMTS of claim 44, wherein the preamble uses 26 known symbols.

46. The CMTS of claim 44, wherein the atypical samples stage does not suppress samples over the en-

tire burst preamble.

47. A method of adjusting the frequency of a cable modem, the cable modem having a transmitter that sends bursts to the demodulator of a cable modem termination system, the bursts having a preamble and data, the demodulator having a received spectrum at its input, the method comprising:

a) commanding the cable modem to operate in ranging mode;
b) providing processed samples derived from the received spectrum, the particular processed sample at the current time being referred to as the current sample;
c) defining a typical sample variance and an acceptable frequency offset limit;
d) generating a running time average of the processed samples;
e) during the burst preamble, including the current sample in the time average;
f) during the burst data, excluding the current sample in the time average when the difference between the current sample and the time average exceeds the typical sample variance;
g) deriving a frequency offset estimate from the time average; and
h) commanding the cable modem to adjust its transmit frequency until the frequency offset estimate is reduced to within the frequency offset limit.

48. The method of claim 47, wherein the preamble uses 26 known symbols.

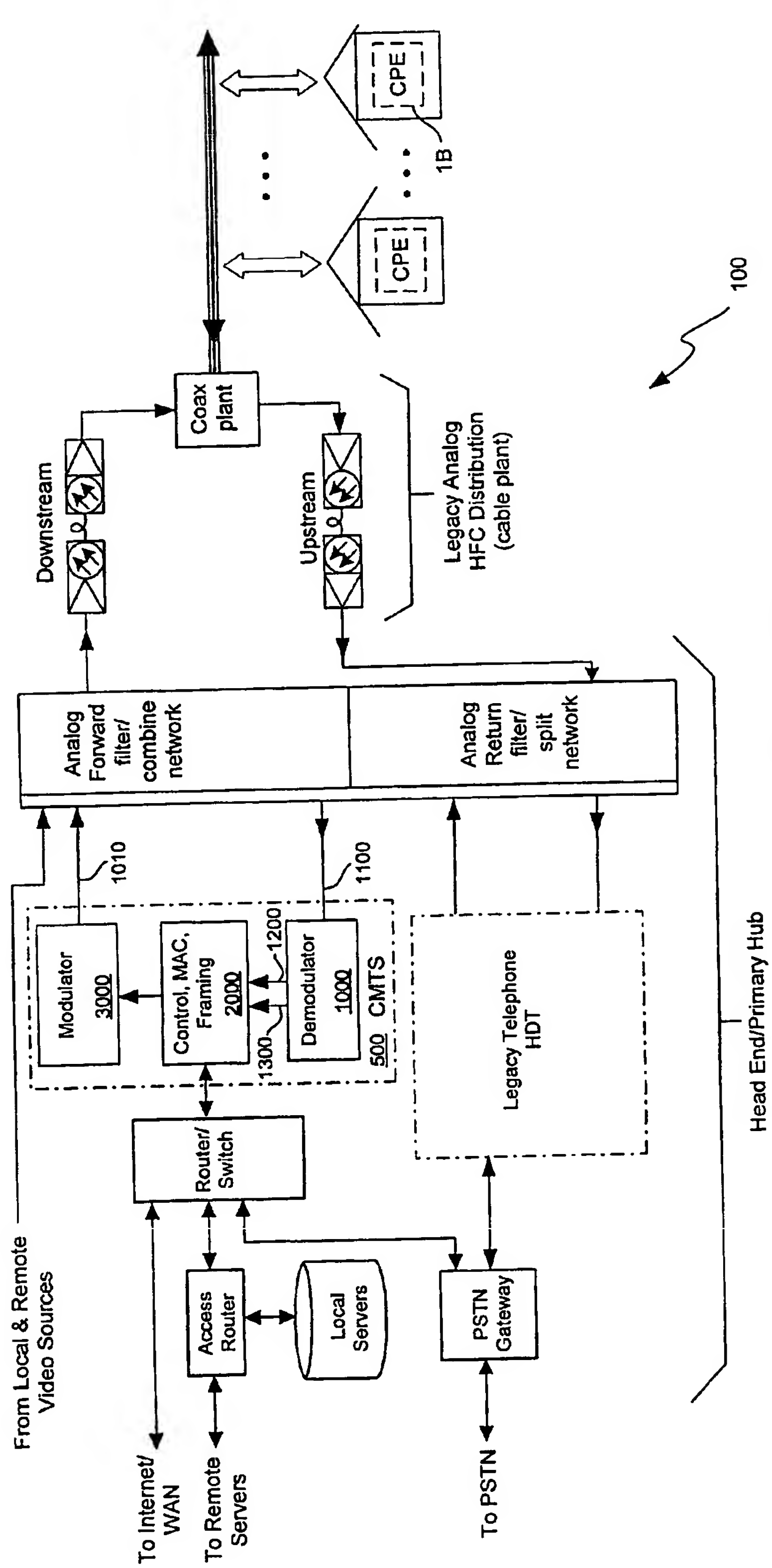
49. The method of claim 47, wherein the processed samples are correlation samples.

50. The method of claim 49, wherein the derivation of the frequency offset estimate includes calculating the phase of the time average.

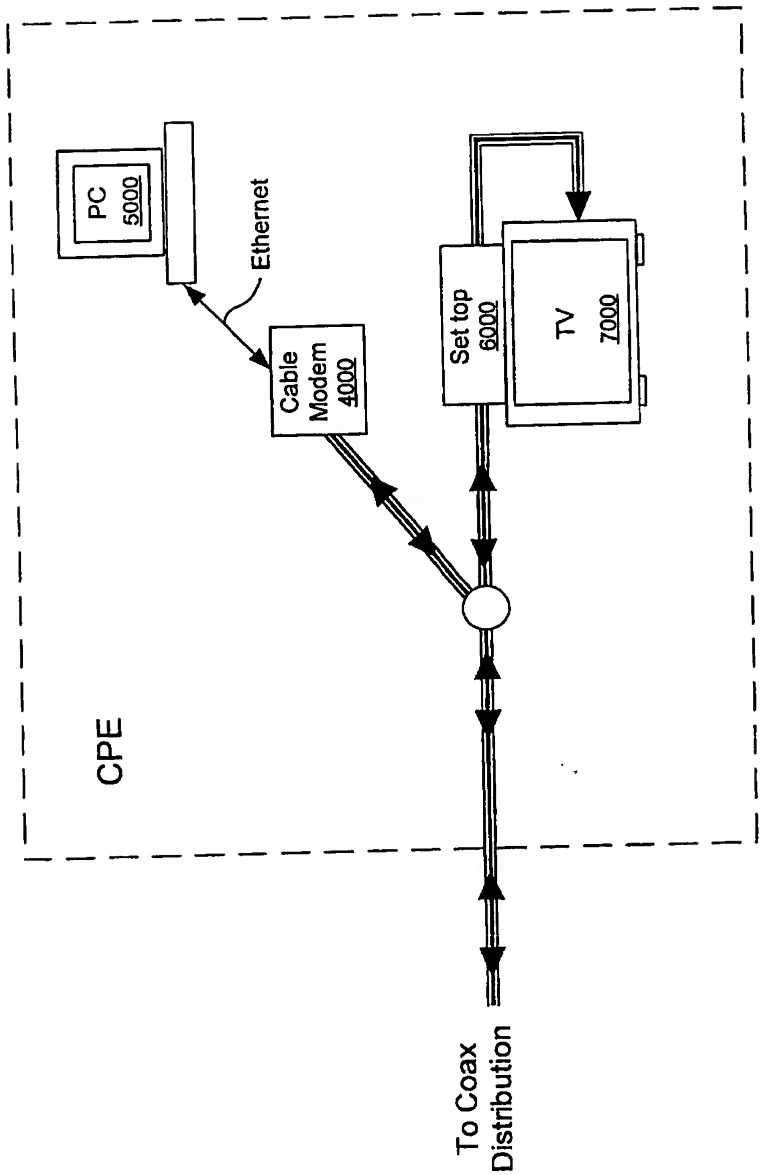
51. The method of claim 50, wherein the derivation of the frequency offset estimate further includes performing normalization on the phase calculation result.

52. The method of claim 47, wherein the processes samples are phase slope samples.

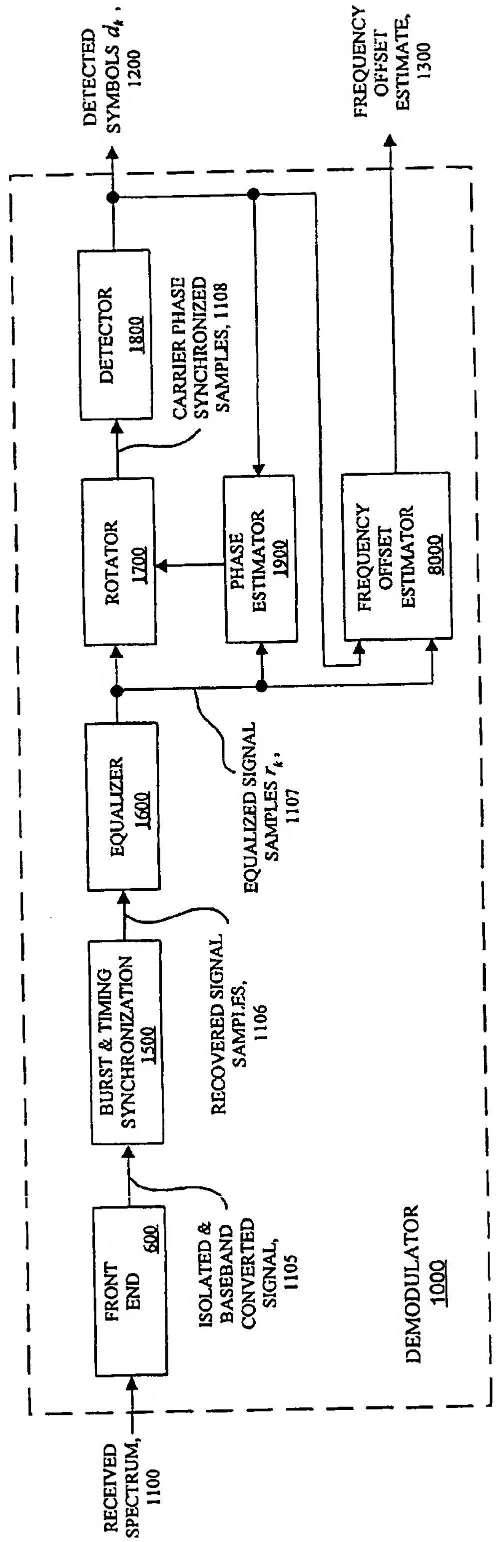
53. The method of claim 52, wherein the derivation of the frequency offset estimate includes performing normalization on the time average.



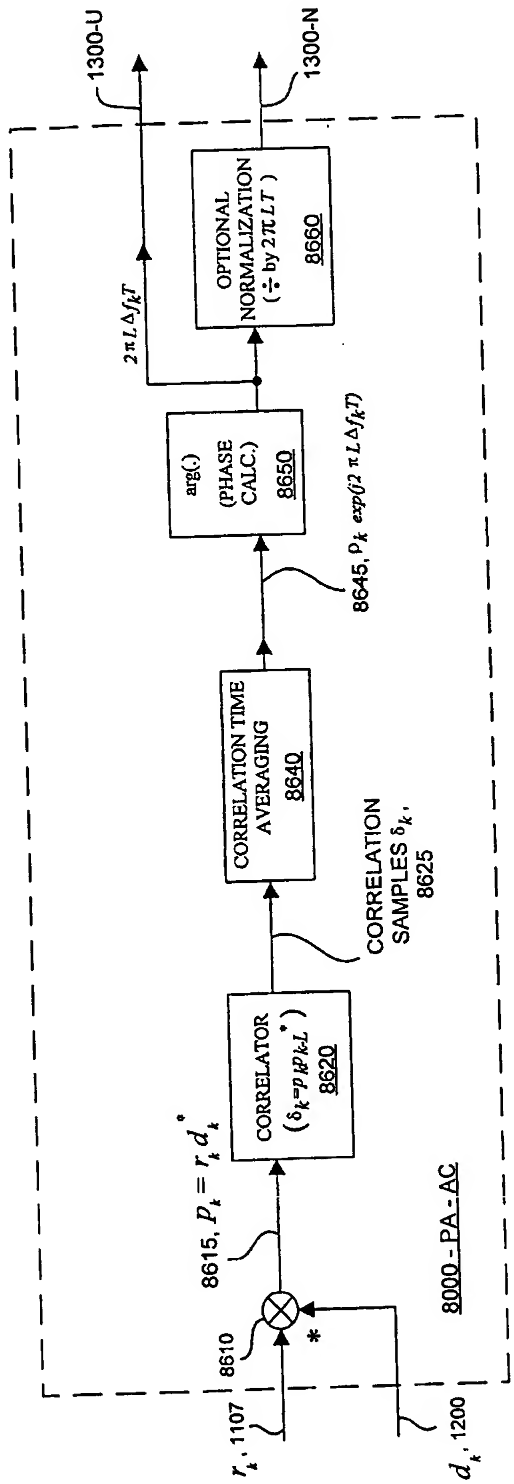
Prior Art
Fig. 1A



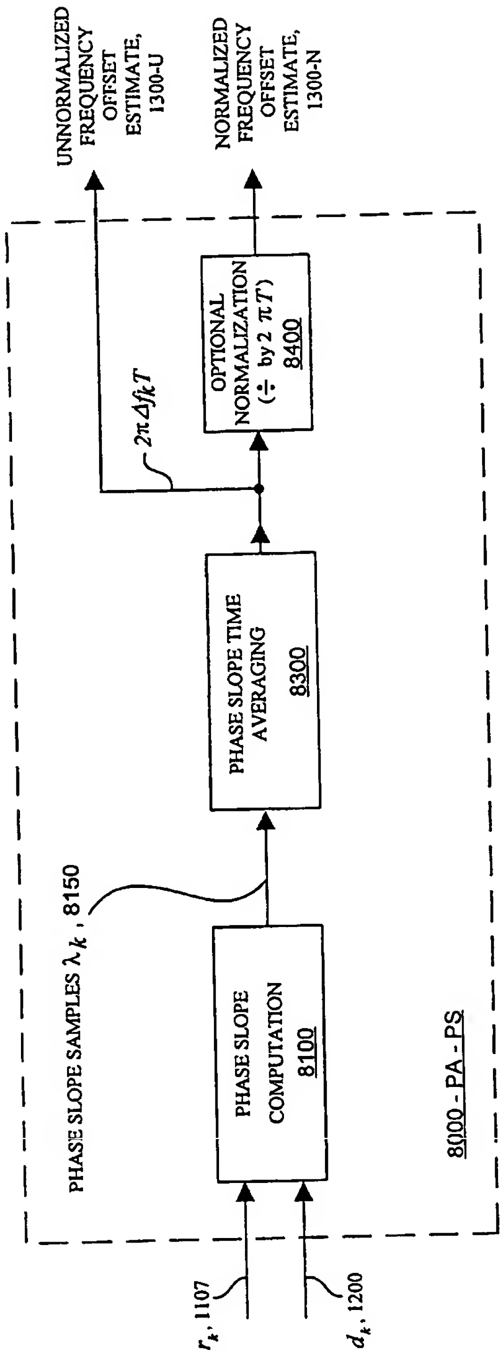
Prior Art
Fig. 1B



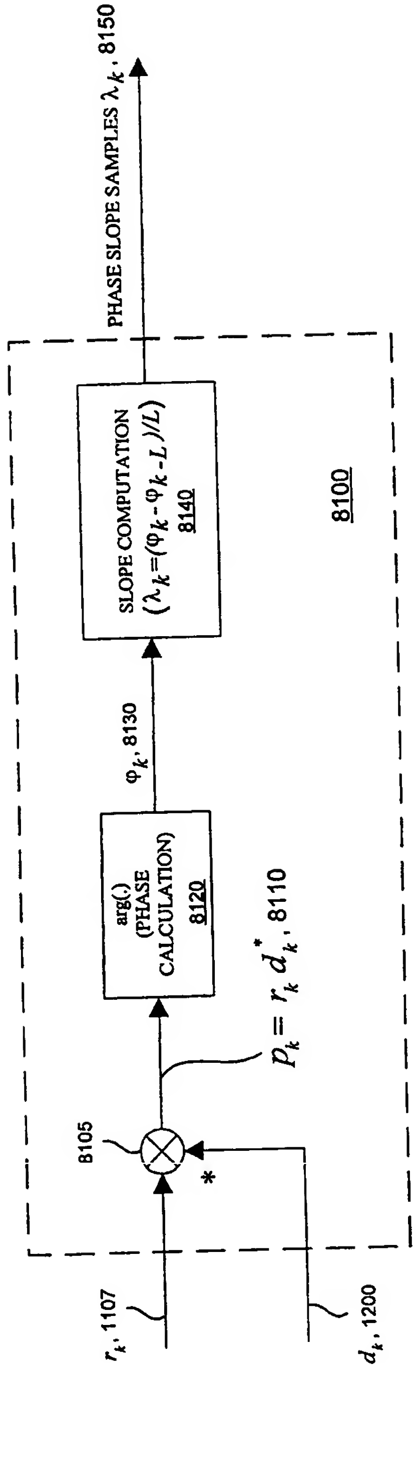
Prior Art
Fig. 2A



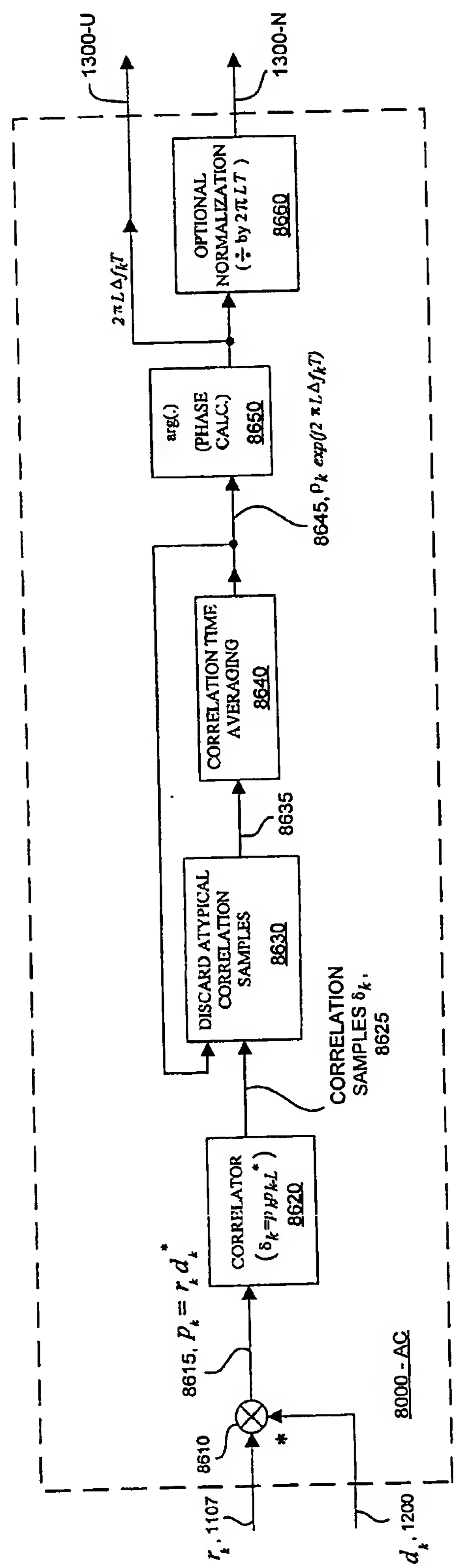
Prior Art
Fig. 2B



Prior Art
Fig. 2C



Prior Art
Fig. 2D



r_k, 1107
d_k, 1200
8610
*
8615, $p_k = r_k d_k^*$
CORRELATOR ($\delta_k = p_k p_{k-L}^*$) 8620
CORRELATION SAMPLES δ_k, 8625
DISCARD ATYPICAL CORRELATION SAMPLES 8630
8635
CORRELATION TIME AVERAGING 8640
8645, $\rho_k \exp(j2\pi L \Delta f_k T)$
arg(.) (PHASE CALC.) 8650
$2\pi L \Delta f_k T$
OPTIONAL NORMALIZATION (÷ by $2\pi L T$) 8660
1300-U
1300-N
8000 - AC

Fig. 3

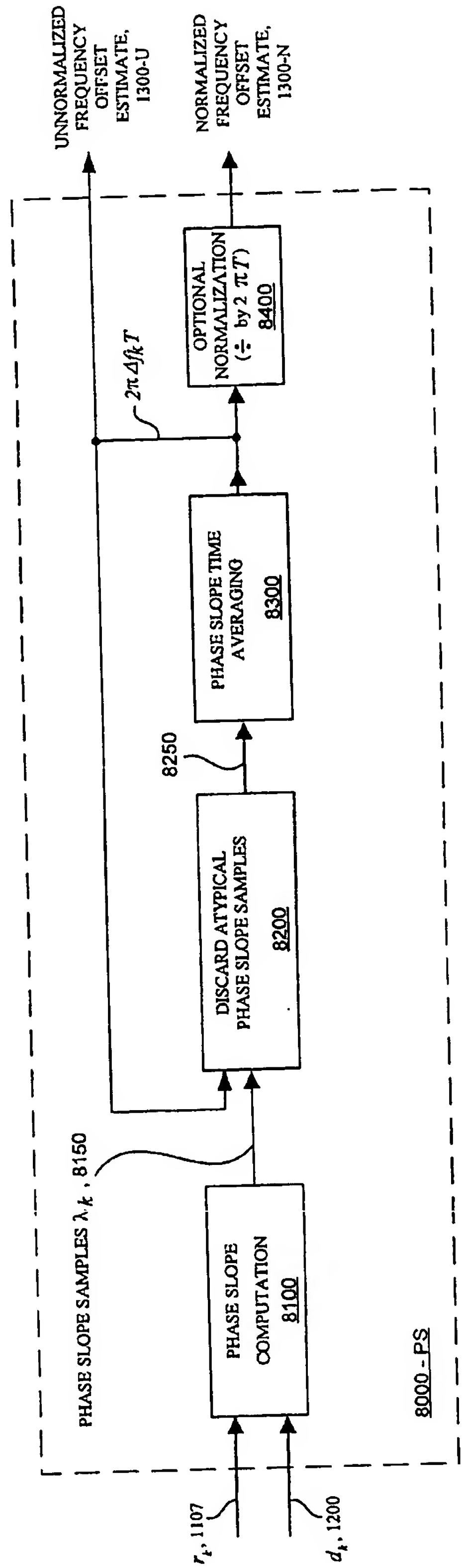

UNNORMALIZED FREQUENCY OFFSET ESTIMATE, 1300-U
NORMALIZED FREQUENCY OFFSET ESTIMATE, 1300-N
OPTIONAL NORMALIZATION (÷ by 2 πT) 8400
2πΔfkT
PHASE SLOPE TIME AVERAGING 8300
8250
DISCARD ATYPICAL PHASE SLOPE SAMPLES 8200
PHASE SLOPE SAMPLES λk , 8150
PHASE SLOPE COMPUTATION 8100
8000 - PS
rk, 1107
dk, 1200

Fig. 4

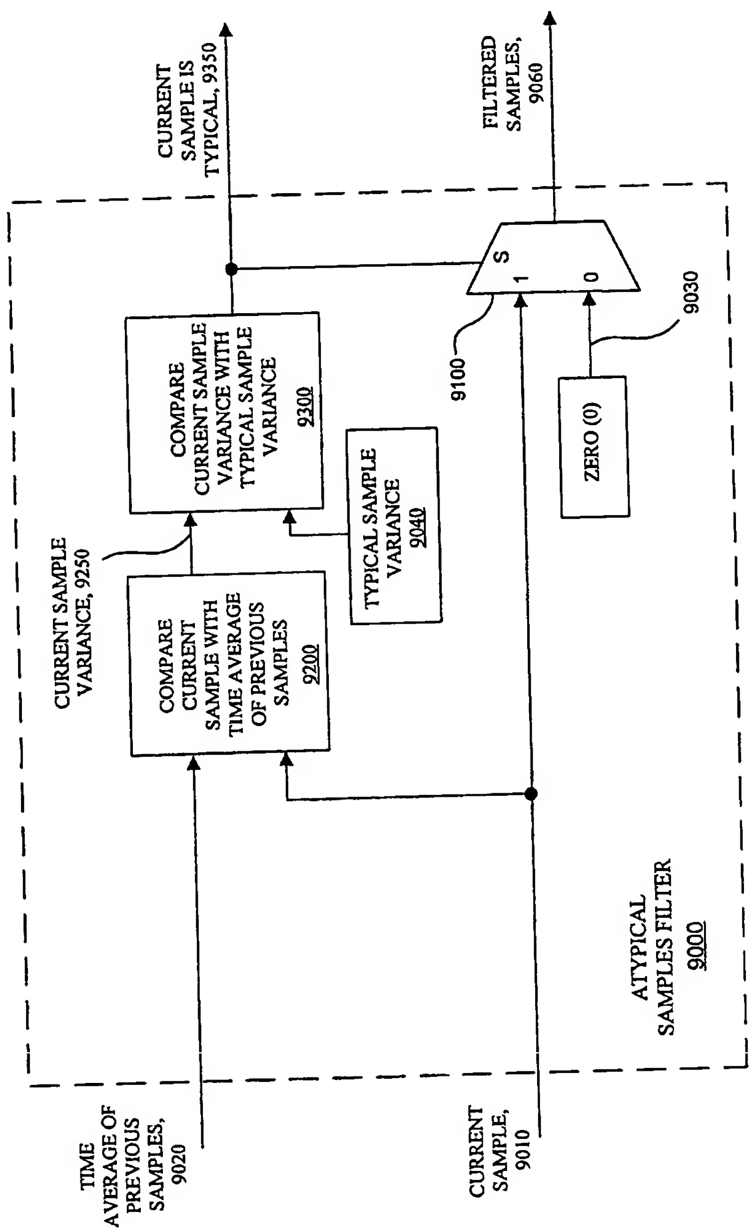

CURRENT SAMPLE IS TYPICAL, 9350
FILTERED SAMPLES, 9060
CURRENT SAMPLE VARIANCE, 9250
COMPARE CURRENT SAMPLE VARIANCE WITH TYPICAL SAMPLE VARIANCE 9300
TYPICAL SAMPLE VARIANCE 9040
COMPARE CURRENT SAMPLE WITH TIME AVERAGE OF PREVIOUS SAMPLES 9200
S
1
0
9100
9030
ZERO (0)
ATYPICAL SAMPLES FILTER 9000
TIME AVERAGE OF PREVIOUS SAMPLES, 9020
CURRENT SAMPLE, 9010

Fig. 5

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 40 0495

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 5 867 539 A (KOSLOV) 2 February 1999 (1999-02-02) * figures 1-3 *	1-53	H04L27/00
X	EP 0 692 896 A (PHILIPS ELECTRONICS; LABORATOIRES D'ELECTONIQUE PHILIPS) 17 January 1996 (1996-01-17) * abstract * * figure 6 *	1-53	
X	EP 0 719 002 A (ALCATEL) 26 June 1996 (1996-06-26) * column 1, line 7 - line 31 * * column 1, line 37 - line 46 *	1-53	
X	EP 0 681 386 A (GEC) 8 November 1995 (1995-11-08) * figure 2 * * column 4, line 45 - column 5, line 4 *	1-53	

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H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 September 2001	Scriven, P

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